PLANNING FOR CLIMATE CHANGE ADAPTATION: HOW DOES THE MTA COMPARE?

A thesis presented to the Faculty of Architecture and Planning at Columbia University in partial fulfillment of the requirements for the degree of Master of Science in Urban Planning.

By Rosemary Bolich

May, 2013

1. INTRODUCTION

When Hurricane Sandy hit the New York City area on October 29, 2012, it caused more damage than a hurricane ever had in the northeast. Indeed, it completely shut down the tri-state area for over 24 hours. The flooding caused by Hurricane Sandy also had a large impact on the transportation infrastructure in the area. In anticipation of the storm, the Metropolitan Transportation Authority of New York (MTA) suspended all service, including New York City Transit, Metro-North Railroad, and Long Island Railroad. New Jersey Transit (NJ Transit) also suspended all service. Both systems had experienced a full suspension of service the year before, when the region was anticipating impact from Hurricane Irene.

Hurricane Irene was a milder storm than expected, though, while Hurricane Sandy caused billions in damage. All seven of the MTA's subway tunnels and its two East River general traffic tunnels were flooded due to an unprecedented storm surge that coincided with high tide in the New York City harbor. NJ Transit suffered much more damage: their Rail Operations Center was flooded, fallen trees pulled down wires, sections of rail were washed out, and several rail stations, including the Hoboken Terminal, were flooded.

An increase in the intensity of extreme weather events such as hurricanes is one outcome of climate change, which is a result of changes in atmospheric composition that have led to warmer temperatures around the world. Planning for climate change involves two approaches: mitigation and adaptation. Mitigation addresses the need to reduce greenhouse gas emissions. Adaptation, on the other hand, is planning to adapt to a new status quo in which the effects of climate change are factored into everyday planning decisions.

Many cities now have plans that address climate change mitigation and adaptation, but public transit agencies must also plan for climate change adaptation in order to protect their infrastructure. There is a great need to plan for this since transportation infrastructure is vulnerable to flooding in many coastal cities. Not only does flooding from storm surge especially threaten rail tracks and subway tunnels, but, over time, sea level rise will intensify storm surge (Jacob, Rosenzweig, Horton, Major, & Gornitz, 2008).

This thesis will compare the plans for climate change adaptation of public transportation agencies in nine American East Coast cities. It will analyze the stage of planning each agency is in and the quality of the plan using a coded evaluation of outcome criteria. I hypothesize that very few, if any, cities will have official climate change adaptation plans due to the lack of resources dedicated to climate change planning, and that the MTA has made more progress in its planning process than other transportation agencies.

2. LITERATURE REVIEW

2.1 Background

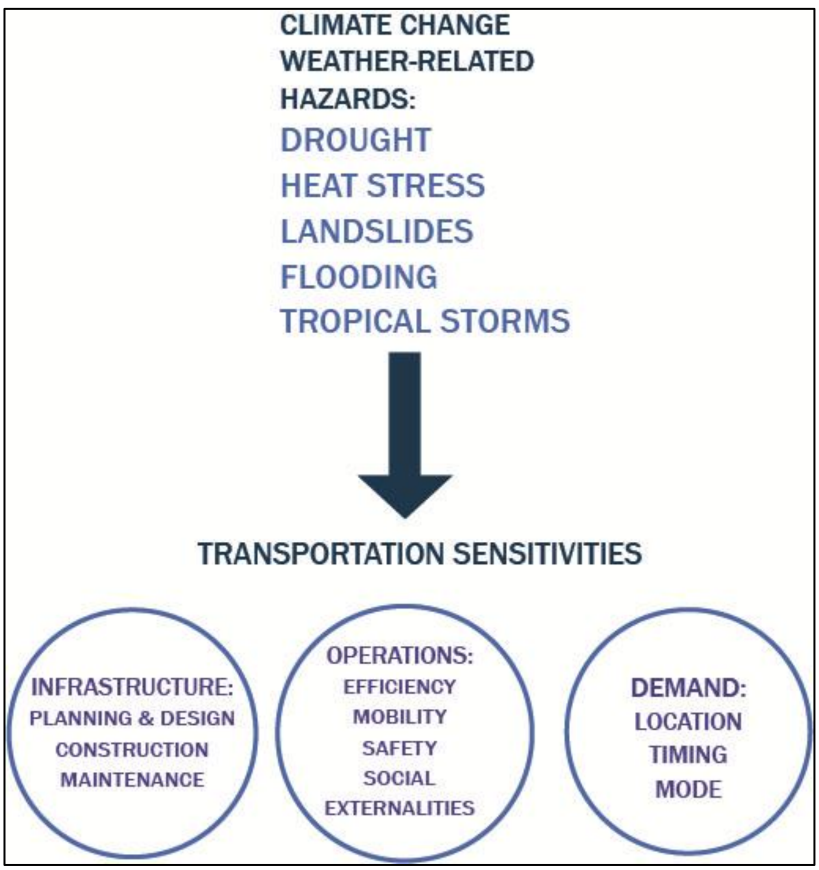
There is undisputed evidence that the global climate is changing. Normal climatic variability is not able to account for the rise in global temperatures since 1950 (Karoly et al., 2003). Future climatic variability will have different effects from region to region. General changes that we can anticipate, however, are fewer cold extremes, more warm extremes, and an increase in precipitation, especially heavy precipitation events (Peterson, McGuirk, Houston, Horvitz, & Wehner, 2008). Climate change will cause destructive storms to increase in their intensity (Jacob et al., 2008), and many scientists believe that they will also increase in frequency. Many climate scientists expect hundred-year storms-- storms that have a 1% chance of occurring during any given year-- will happen more often.

The Transportation Research Board (TRB) states that flooding is potentially the greatest overall impact of a changing climate because of the combination of sea level rise, storm surge, and land subsidence that threatens coastal areas (National Research Council Committee on Climate Change & US Transportation, 2008). Low-lying infrastructure is especially vulnerable to increased precipitation and flooding, which means that much of the transportation infrastructure on the East

Coast is vulnerable due not only to its proximity to the coast, but also to historical development patterns.

Studies have been done on potential general impacts of climate change and impacts for different regions (e.g. Peterson et al. (2008), McCarthy, Canziani, Leary, Dokken, and White (2001), Metropolitan East Coast Assessment). Though the potential effects of climate change on transportation specifically have not been studied widely, researchers who have studied the topic agree that climate change will have an impact on all types of transportation infrastructure (Mills & Andrey, 2002). They all agree that climate change will affect transportation infrastructure in multiple ways. Figure 1 shows what some of these impacts would be. Climatic variability such as changing freeze-thaw cycles, increased precipitation, and more frequent intense storms will affect the infrastructure, operations, and demand of transportation systems.

Figure 1. From (Mills & Andrey, 2002).



It is easiest to understand the impact of climatic changes on infrastructure: increased precipitation and changing freeze-thaw cycles can change the life span of infrastructure, whether it is a gradual or quick degradation. Change should also affect the planning and design of infrastructure; planners and engineers must incorporate the need to adapt to a changing climate into their designs for capital construction and their plans for maintenance. Climate change will also affect the operations and demand of transportation systems. Extreme weather events have the largest impact on operations, since they have the ability to shut down a system for a day or days. The table in figure 2 includes these impacts of increased precipitation.

Figure 2. Adapted from (Meyer, Amekudzi, & O'Har, 2010).

Climate change result	Impact
Increased precipitation	Increased incidence of flooding Accelerated asset deterioration
Sea level rise	Flooding of infrastructure Greater storm surges
More extreme weather events	Damage to infrastructure Interruption to service

Flooding is a significant threat to New York City. Climate scientist Rae Zimmerman believes that increased flood elevations may be the first effect of climate change in New York City (2002). Another important change that scientists anticipate is the increase in the occurrence of extreme weather events (Peterson et al., 2008). As demonstrated by hurricanes every year, extreme weather poses much more of a threat than generally increased precipitation because of the capacity to cause widespread flooding. This applies to the rest of the United States as well: generally increased climate variability is far less of a threat because our transportation systems already consider a certain range of variability. The design of infrastructure factors in a range of temperatures that components will be exposed to, and considers that it will be exposed to precipitation. Therefore, it is extreme weather events that are the true threat, as they have more potential to really affect transportation systems. In order to be better prepared for future flooding, public transit agencies around the country need to factor climate change into their short- and long-term planning and begin to adapt their systems.

2.2 Adaptation

Planners and other city officials must take the changing climate into consideration as they plan for the future. As mentioned previously, there are two approaches to planning for climate change. The first is mitigation, which involves decreasing the amount of greenhouse gases that we produce. Climate change mitigation is important, but its impact will not be realized until far in the future. The second approach, adaptation, has more short-term effects.

Adaptation to climate change, as defined by the Intergovernmental Panel on Climate Change (IPCC) in 2001, is an adjustment in ecological, social or economic systems in response to observed or expected changes in climatic stimuli and their effects and impacts in order to alleviate adverse impacts of change (McCarthy, Canziani, Leary, Dokken, & White, 2001). The IPCC wrote that adaptation is reactive or anticipatory, but Adger et al. argued that is instead both reactive and anticipatory as it is often catalyzed by events such as extreme weather and focuses on mitigating the potential impacts of those events in the future (Adger, Arnell, & Tompkins, 2005; McCarthy et al., 2001).

Climate change adaptation for transportation infrastructure can take many different forms. One easy way that transportation agencies can adapt their infrastructure is via its normal life span. Because transportation infrastructure has a finite service lifespan, it can be cost-effective to simply replace or adapt infrastructure at the end of that life (Mills & Andrey, 2002). If the need to adapt is more immediate, however, the cost of upgrading or replacing can be more prohibitive.

Cost of adaptation measures is often a barrier to implementing them. Short-term adaptation actions can be relatively inexpensive, but long-term adaptation strategy can involve many costintensive objectives, which is an obvious deterrent to long-term adaptation planning. It is important for city officials to keep in mind the benefits of adaptation planning compared to the costs.

Another measure that prepares an organization for climate change adaptation is to complete an asset inventory. The Transportation Research Board recommends conducting an inventory because it is a low-cost way to start planning for adaptation (National Research Council Committee on Climate Change & US Transportation, 2008). An inventory serves multiple purposes. It assesses what infrastructure is the most vulnerable to changing weather, but also creates a record of where each infrastructure component is in its lifespan and the timeline for replacing or repairing it. Overall, an inventory helps an agency to prioritize different parts of its system.

The TRB also recommends updating design standards for infrastructure so that the standards reflect the challenges posed by the climate in a given region. Much of the infrastructure in the eastern United States was built in the 1960s and 1970s, and would therefore not meet modern design standards. As such, old infrastructure that was built in the 1960s or 1970s may no longer be able to withstand a 100-year storm (Peterson et al., 2008). This is an important issue to address, but it is also a relatively easy one to address.

Relatedly, estimates of 100-year storms may also be out of date. As discussed above, precipitation poses a threat to transportation infrastructure, so the intensity, frequency, and duration of past precipitation events must be analyzed. Updating estimates of 100-year storms is urgent, especially as storms continue to increase in strength and frequency. Governments and agencies may also want to consider planning for even more extreme scenarios (those that would be considered a 1,000-year or 10,000-year storm) in order to better protect both infrastructure and populations in vulnerable areas.

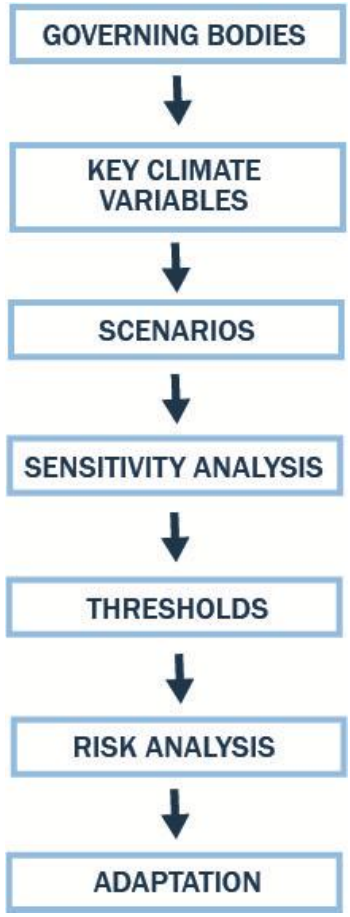
The above are adaptation measures that are relatively easy and inexpensive to implement. More formal adaptation planning involves risk assessment. A typical risk assessment framework, as modified by Jones to include stakeholder input, is outlined in Figure 3 (2001). The risk analysis and adaptation model begins with key climate variables as determined by the IPCC, from which climatologists have developed various long-term climate scenarios. Scientists and planners then develop different sensitivity analyses, based on the biophysical and behavioral thresholds of the community for which they are planning. While other thresholds have an impact on transportation systems, behavioral thresholds refer to a level of performance, and are therefore particularly applicable to their adaptation. Once thresholds are determined, a risk analysis can be done.

Risk is a combination of two factors, the probability that an adverse event will occur, and the consequences of that event (Jones, 2001). Risk assessment analyzes climate scenarios to determine what outcomes are likely, which allows informed adaptation decisions to be made. The process can lead to both autonomous adaptations and planned adaptations. Throughout the entire process, stakeholders are involved and consulted.

Vulnerability is another key component of risk assessment. According to the IPCC, vulnerability is "the extent to which a natural or social system is susceptible to sustaining damage from climate change, [and is] a function of sensitivity of a system to changes in climate…adaptive capacity…and exposure to climatic hazards" (McCarthy et al., 2001).

While risk is assessed more in terms of a whole transportation system, vulnerability can be determined separately for each piece of infrastructure, and can therefore be helpful in setting priorities.

Figure 3. Adapted from (Jones, 2001).



Another adaptation strategy is developing an asset management plan. Transportation asset management is essentially an enhanced inventory that can easily be used for adaptation planning. According to American Association of State Highway and Transportation Officials (AASHTO), transportation asset management is “a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their life cycle” (NCHRP, 2002). Generic asset management systems incorporate goals and policies, inventory, condition assessment and performance monitoring, and long-range planning, among other aspects (Meyer et al., 2010). Meyer et al emphasized the usefulness of asset management for climate change adaptation by factoring in system vulnerability (2010). Further applications of asset management for climate change are shown in figure 4.

Figure 4. From (Meyer et al., 2010)

Asset Management System Component	Monitoring Techniques and Adaptation Strategies
Goals and policies	Incorporate climate change considerations into asset management goals and policies; these could be general statements concerning adequate attention of potential issues, or targeted statements at specific types of vulnerabilities (e.g., sea level rise).
Asset inventory	Mapping, potentially using GIS, of infrastructure assets in vulnerable areas; inventory critical assets that are susceptible to climate change impacts.
Condition assessment and performance modeling	Monitor asset condition in conjunction with environmental conditions (e.g., temperature, precipitation, winds) to determine if climate change affects performance; incorporating risk appraisal into performance modeling and assessment; identification of high risk areas and highly vulnerable assets. Use of "smart" technologies to monitor the health of infrastructure assets.
Alternatives evaluation and program optimization	Include alternatives that use probabilistic design procedures to account for the uncertainties of climate change; possible application of climate change–related evaluation criteria, smart materials, mitigation strategies, and hazard avoidance approaches.
Short- and long-range plans	Incorporate climate change considerations into activities outlined in short- and long-range plans; incorporate climate change into design guidelines; establish appropriate mitigation strategies and agency responsibilities.
Program implementation	Include appropriate climate change strategies into program implementation; determine if agency is actually achieving its climate change adaptation and monitoring goals.
Performance monitoring	Monitor asset management system to ensure that it is effectively responding to climate change; possible use of climate change–related performance measures; "triggering" measures used to identify when an asset or asset category has reached some critical level.

Inventories, risk assessment, and asset management plans are common approaches that are taken by agencies and governments to plan for climate change adaptation. A comprehensive adaptation plan could include all of these components since they complement each other. Planning literature provides guidelines for developing high-quality hazard mitigation plans. According to Kaiser, Godschalk and Chapin, the three characteristics of plan quality are a strong factual basis, clearly articulated goals, and appropriately directed policies (1995). In his analysis of hazard mitigation plans over eight years, Brody emphasized that plans of this type should be updated regularly in order to reflect what planners and other experts have learned (2003).

Baker et al remind planners of two important ideas to keep in mind when drafting or evaluating adaptation plans. The first is that adaptation planning at the local government level does not occur independent of higher levels of government. This means that, while planning happens at the local level—and climate change adaptation is especially a local issue—federal regulations can still have an impact on planning decisions. The second is that, at the local scale, "vulnerability to climate change is not only determined by its climate impacts, but is also largely subject to a number of non-climate determinants of vulnerability" (Baker, Peterson, Brown, & McAlpine, 2012). Analysis of these non-climate variables play an important role in projecting vulnerabilities, but they have been found to be absent in local climate change adaptation planning efforts (Baker et al., 2012).

Plan evaluation is not only important to assess quality, but can also be used to assess plan implementation (Brody, 2003). Plan evaluation is an important process, especially since climate change adaptation planning is a relatively young concept. Tracking plan quality over time is also critical, as "understanding how planners and communities learn and adapt… may provide important insights into how plan quality can be strengthened to address repetitive hazardous events more effectively" (Brody, 2003). The literature points to a positive conclusion: plan evaluation is a very useful process for improving the quality of plans over time, and the iterative process of evaluation allows planners to plan more successfully for hazard mitigation.

3. DATA & METHODOLOGY

This study will examine the climate change adaptation plans of public transportation agencies in Boston, New York City, New Jersey, Baltimore, Washington D.C., Norfolk-Hampton Roads-Virginia Beach, Jacksonville, Miami, and New Orleans. These cities were selected because they all meet the following criteria:

- One of the 100 most populated cities in the United States;
- In the Eastern U.S.;
- According to FEMA flood maps, parts of the city are in a floodplain;
- Have rail public transportation.

Norfolk and Virginia Beach are part of the same metropolitan statistical area, or MSA, and share a public transportation system, so they were combined. New Jersey is in this study as a state because Newark and Jersey City are in the 100 largest cities in the U.S., and New Jersey Transit serves both those cities and many other locations.

For public transportation agencies that do not have a climate change adaptation plan, other documents were assessed. The documents used for this study consisted of special reports commissioned by transit agencies and city master plans, among other examples. This was necessary in order to compare efforts undertaken in different East Coast cities. The documents were gathered from publicly accessible websites by searching for the name of the transportation agency or the city and the phrase "climate change." In order to compare adaptation planning across public transportation agencies and cities, this study analyzed the planning steps the agencies have taken.

The study will compare climate change adaptation planning efforts using a coded evaluation. I will first analyze existing literature and climate change planning documents of the cities being studied. Based on this information, outcome criteria will be determined. Outcome criteria are selected by assessing outcome statements, i.e. the goal or goals of the plan (Baker et al., 2012). The outcome criteria for this study are 1) completing an asset inventory; 2) adopting an adaptation policy; 3) completing a risk assessment; 4) developing a plan for protecting infrastructure from flooding; 5) creating a plan for improving communication before and during extreme weather events.

Criteria will then be evaluated in two categories, overall progress and plan quality. Progress will be determined by characterizing the nature of the planning documents, and assigning a stage to the plan (see figure 5). Stages of progress were developed by building upon the typical awareness-analysis-action progression of climate change policy as described by Moser and Luers (2008). The stages cover a range of preparedness from acknowledgement of climate change as a challenge to detailed planning for adaptation. Quality of plans will be evaluated on the 5-point scale (see figure 6) used by Baker et al. in their study of local climate change adaptation plans.

Figure 5. Progression of planning stages.

Stage	Description
Awareness	The agency has acknowledged that climate change will have an impact on the future.
Analysis	The agency has commissioned reports or other documents about climate change adaptation as it may effect their organization.
Actions	The reports or other documents about climate change adaptation and the agency have specific recommendations for future action.
Adoption	The agency has an official plan for climate change adaptation.
Adoption with action	The official plan has specific steps for future actions.

Figure 6. Coding criteria, from (Baker et al., 2012)

Code number	Description
0	No evidence of the criterion throughout the plan.
1	The criterion is acknowledged, but lacks further definition and does not provide detail.
2	The criterion is mentioned and includes a moderate level of detail. However, it is entirely descriptive and lacks local application and analysis.
3	The criterion is mentioned and includes a limited level of locally specific application using local climate scenario modelling, exposure, vulnerability and/or risk assessments, maps, local historical data, or fieldwork. However, it is largely descriptive.
4	A detailed analysis of the criterion is provided and it is addressed in a locally specific manner using a variety of tools such as vulnerability, exposure and/or risk assessments, maps, fieldwork, GIS analysis and modelling and local climate scenario modelling.

4. FINDINGS

Few of the public transit agencies included in this study have official climate change plans, as shown in Table 1. Instead, the study found a range of documents that may inform a transit agency's planning for the future climate.

Table 1. Availability of transit agency climate change adaptation documents.

City	Agency	Adaptation-related document
Boston	Massachusetts Bay Transportation Authority	
New York City	Metropolitan Transportation Authority	X
New Jersey	New Jersey Transit	X
Baltimore	Maryland Transit Administration	
Washington, DC	Washington Metropolitan Area Transit Authority	X
Norfolk-Hampton Roads-Virginia Beach	Hampton Roads Transit	X
Jacksonville	Jacksonville Transportation Authority	
Miami	Miami-Dade Transit	
New Orleans	New Orleans Regional Transit Authority	

The public transit agencies in Boston, Baltimore, Jacksonville, Miami, and New Orleans did not have any documents relating to climate change adaptation and were therefore not coded for qualitative evaluation.

As previously mentioned, the MTA in New York City operates subway, commuter rail, and bus service. It serves the New York City, counties north of the city, and two counties in Connecticut, and it has the highest ridership in the United States. For this study, the Blue Ribbon Sustainability Commission (BRSC) report was evaluated. The MTA has not produced another report or plan relating to climate change since it was published.

New Jersey Transit (NJT) is a statewide public transit agency and the largest statewide transit agency in the United States. It operates light rail, commuter rail, and bus service and is the third busiest transit provider in the country. NJT commissioned a report on resilience and climate change in 2012.

Washington Metropolitan Area Transit Authority (WMATA) is a tri-jurisdictional agency formed by Maryland, Virginia, and Washington, D.C. and has the second highest ridership in the country. As its name suggests, it serves the Washington, D.C. metropolitan area. Like NJT, it operates light rail, commuter rail, and bus service. WMATA did not have any documents that address the challenges of climate change, but mentioned extreme weather in its strategic plan, which is the document that was evaluated.

Hampton Roads Transit (HRT) has a service area that includes seven cities—the largest being Virginia Beach, Norfolk, and Newport News—and 1.6 million residents. It operates light rail, bus, and ferry service. The Hampton Roads area has been part of an FHWA study, and the final report from that study was assessed. While HRT was not an author of the study, the Hampton Roads Transportation Planning Organization (HRTPO), the metropolitan planning organization for the region, was involved. Since it was a part of a federal program, the study addressed all modes of transportation.

Table 2. Coding worksheet.

Information				**Progress**
City	**Author**	**Type of document**	**Year**	**Planning Stage**
New York	MTA	Sustainability Report	2008	Actions
New Jersey	Consultant	Report regarding climate change resilience	2012	Analysis
Washington, D.C.	WMATA	Strategic Plan	2012	Awareness
Norfolk-Hampton Roads-Viriginia Beach	Virginia DOT, Hampton Roads Transportation Planning Organization	FHWA Program report	2011	Analysis

	Criteria				
City	**Asset inventory is completed.**	**Adaptation policy is adopted.**	**Risk assessment is completed.**	**Plan for protecting infrastructure from flooding is developed.**	**Plan for improved communication before and during weather events is created.**
New York	4	4	4	0	1
New Jersey	0	0	1	1	0
Washington, D.C.	0	1	0	1	0
Norfolk-Hampton Roads-Viriginia Beach	4	0	4	0	0

Table 3. Total scores.

City/Area	Score
New York City	13
New Jersey	2
Washington, D.C.	2
Hampton Roads MSA	8

As previously mentioned, none of the transit agencies are in the adoption stage; none of the documents evaluated in this study are official transit agency plans. Instead, three of the transit agencies have reports on what the effects of climate change could be on their infrastructure, and how they can adapt to an increased risk of flooding. Out of a total possible score of 20, the MTA's report received 13 and the Hampton Roads report received 8, while NJ Transit and WMATA scored much lower.

The New York City MTA scored the highest in the coded evaluation, and was the only agency that was determined to be in the Action stage. The MTA received the highest score for three outcome criteria: asset inventory, adaptation policy, and risk assessment. The BRSC report, however, had no goal of creating a plan to protect infrastructure for flooding. Lastly, despite the fact that the need for enhanced communication protocols is included in the BRSC, there was little detail, and the MTA received a low score for that criteria. Overall, it was the only document in which communication was included as a goal.

The Hampton Roads-Norfolk-Virginia Beach MSA received the next highest score. The FHWA report, authored by Viriginia Department of Transportation, University of Virginia, and HRTPO is a thorough study of the threat that flooding poses to the Hampton Roads area. However, it did not suggest that any planning entity in the area adopt an adaptation plan, nor did it emphasize the need to plan for the protection of infrastructure. The report evaluated the risk of flooding, but had very few suggestions as to how to mitigate the hazard.

A lack of suggestions or goals was common across documents analyzed for this study. While the documents for New Jersey and Washington, D.C. were different, both failed to set goals for the transit agency and therefore received low scores. WMATA's strategic plan mentioned that extreme weather would have an impact on transportation infrastructure. The report commissioned by New Jersey transit detailed the threat that flooding posed to NJT infrastructure, but included very few recommendations for how to respond to that threat. Overall, the documents assessed contained little detail about both the hazards posed to transit infrastructure and the agency's goals for addressing the vulnerability of that infrastructure, which accounts for the low scores.

5. ANALYSIS

Similar results were found across many of the planning documents assessed for this study. The most obvious finding is that none of the transit agencies have an official climate change adaptation plan. The MTA came closest on this account, but the action steps in the BRSC report are just recommendations. Public transit agencies need to plan for adaptation so that they are prepared for extreme weather events, which, in the range of cities chosen for this study, include a high risk of flooding. For more on the importance of planning, see the discussion on New York City and New Jersey preparedness below.

The first stage of the planning process is awareness, which is the corresponding stage for two out of four of the documents assessed. Many agencies or other government entities seem content to acknowledge that climate change could impact infrastructure and not provide any goals for hazard mitigation. Another, related, similarity is the reluctance of transit agencies to outline any recommended actions for dealing with the changing climate. Agencies are missing steps that are inexpensive to undertake, such as developing an enhanced communication plan or inventorying assets with a focus on what infrastructure is vulnerable to flood risk.

What accounts for this lack of adaptation goal-setting? There are a few reasons why public transit agencies may not be planning for climate change adaptation. A very likely reason is a lack of funding. This is not surprising, as nearly all public transit agencies in the United States operate on a deficit, including the MTA, which has the highest farebox recovery percentage in the country. When budgets are tight, a transit agency is not going to undertake a climate change planning process instead of performing routine maintenance. Transit agencies have little room to set their priorities, especially since budgets are so constrained by reduced state funding. An alternative is that transit agencies are planning for adaptation via their capital construction plans, which is a formal way of performing maintenance and new construction according to vulnerability, as discussed above. The problem with this, of course, is the slow pace at which a transit agency would adapt its system if the only measures taken were via its capital plan.

Another possible reason for the lack of climate change planning is that public transportation is considered to be relatively unimportant in the United States. This possibility is very much tied in with a lack of funding to transit agencies. A small percentage of Americans use public transit regularly, and though it is a public good, it is rarely a priority for government officials at any level from local to federal. However, public transit is an important service on East Coast, and it is unlikely that city officials are willing to entirely ignore risks posed to their systems.

Furthermore, it is possible that climate change adaptation planning is experiencing a two-fold freerider problem. The first is a traditional freerider problem: since some cities and regions are developing climate change plans or addressing mitigation and adaptation in their city master plans, the local public transit agency may think that it is unnecessary to duplicate their effort. This could certainly account for some of the lack of transit agency planning in this study, as city, region, or state climate change adaptation documents exist for most of the cities or states included in this study. The second is more nuanced and takes into account the role of state and federal government. The ability to receive state and federal aid in the wake of an extreme weather event combined with the fact that they are insured may be deterring public transit agencies from developing climate change adaptation plans. The most likely answer for the lack of adaptation planning observed is a combination of the above reasons.

5.1 New York City and New Jersey: A comparison

Officials in New York City and New Jersey knew that there was a chance that transit infrastructure would be damaged by Hurricane Sandy. Both the MTA and NJ Transit had commissioned studies to analyze the vulnerability of their infrastructure. The MTA was aware of the chance that the subway tunnels could flood, as the possibility was detailed in a 2011 report written by a team of scholars from Columbia University for New York State Energy Research and Development Authority (NYSERDA) (New York State Energy Research and Development Authority, 2011). The report showed which subway tunnels were vulnerable to flooding due to the elevation of their ventilation and station openings, and showed the predicted consequences of a hundred-year storm, which was considered to be a category 1 or 2 hurricane. Hurricane Sandy was a category 1 hurricane combined with high tide.

Both the MTA's and NJT's transportation infrastructure is vulnerable to extreme weather and will continue to be threatened by climate change. Low-lying infrastructure in New York City, New Jersey and other coastal areas will be under increased threat of flooding due to a dual threat of storm surge and, more gradually, sea level rise. While much has been written about the threat that climate change poses to various systems in New York City, Hurricane Sandy has proved to New York and the rest of the United States that planning and preparing for extreme weather events is of the utmost importance.

The extent to which transit agencies and the cities in which they operate plan for climate change is very important, since so many other aspects of daily life depend on transportation (Titus, 2002). In New York City, this is especially true. Steps have been taken toward a city-level climate change plan. PlaNYC, published in 2007, addresses climate change adaptation and recommends measures that the city can take. In order to work toward those goals, Mayor Michael Bloomberg created the New York City Panel on Climate Change (NPCC) in 2008. In 2010, in conjunction with the Mayor's Office of Long-Term Planning and Sustainability, the NPCC published a report on risk-analysis-based climate change adaptation. Most recently, Mayor Bloomberg made the NPCC a permanent advisory panel (Navarro, 2012).

The MTA has taken fewer steps than the City to study and plan for climate change adaptation, but it has been working to evaluate what climate change means for its infrastructure and operations. In August 2007, a storm system hit New York City and caused a temporary suspension of some subway service. At the time, it was the most extreme impact a storm had had on the public transportation system to date. A review of the agency's operating systems and procedures was undertaken to ascertain what could be done to reduce its systematic and operational vulnerabilities to extreme weather events (Metropolitan Transportation Authority, 2007). The findings were summarized in a report that identified measures to be taken in three categories: operations, engineering, and communications. Across the categories, the MTA identified 16 measures it could take:

- Create early warning and response capability
- Create an MTA Emergency Response Center
- Revise agency storm operating protocols
  - Standardize storm category designations
  - Formalize interagency coordination/notification plans
  - Develop bus service alternative plan
  - Coordinate interagency service alternatives
  - Standardize procedures for communicating with operating personnel, customers and other external stakeholders
- Dramatically improve customer information
- Develop capacity for near to real-time email and text messaging service alerts
- Provide cell phone service on subway platforms
- Increase website capacity, clarity, and access to service alerts

- Improve communication between ops centers and field personnel
- Advance public address and video screens technologies to better communicate with customers in-system
- Expand MTA's current inventory of wireless video displays
- Conduct six-month progress review

Spurred by the suspension of MTA service caused by the 2007 storm, Governor Eliot Spitzer created the MTA Blue Ribbon Sustainability Commission (BRSC). In 2008 they issued a report on different areas of environmental policy as they relate to the MTA. Part of this was a report on adapting to climate change, entitled *MTA Adaptations to Climate Change: A Categorical Imperative*, by a group of scientists from Columbia University. The longer report on adaptation was summarized in the climate change adaptation section of the BRSC report, which was also published in 2008.

MTA Adaptations to Climate Change emphasized adaptations in the same three areas as the review in 2008: operations, engineering, and communications. It also evaluated other management approaches the MTA could take as part of a climate change adaptation policy. In its recommendations section, the report highlighted deficiencies in the MTA's policies/planning and made targeted recommendations with dates by which they should be fulfilled. Recommendations include the adoption of a basic adaptation policy by mid-2009, the establishment of a climate database with future climatic trends by the end of 2010, the completion of a risk assessment vis-à-vis climate change by 2012, and the adoption of a climate change adaptation master plan by 2015 (Jacob et al., 2008).

NJ Transit had also studied the vulnerability of its infrastructure in a report developed by a consultancy, but the final product stands in stark contrast to the planning efforts undertaken by the MTA. The report, entitled "Resilience of NJ Transit Assets to Climate Impacts," was published in June 2012 and outlined the risks that extreme weather posed to NJ Transit's stationary infrastructure. It correctly predicted that many areas, including rail yards in the Meadowlands and Hoboken where NJ Transit stored stock before the storm, would flood (Thomson, 2012).

The MTA's BRSC report is the clear model for other American transit agencies. It is comprehensive and each section of the report has a longer, more detailed report that further explores researchers' findings. However, it would be ideal to see the MTA adopt it as official policy. Not only is it necessary for the agency's future, but the proposed actions mean little if the plan is not official agency policy.

Hurricane Sandy made the need to further plan for climate change adaptation clear. Scientists had already written about the threat a high storm surge would pose to the New York City subway system, due to the abundance of infrastructure at flood-prone elevation (Jacob et al., 2008). The planning that the MTA had to prepare for an extreme weather event undoubtedly helped it recover quickly. A loss of electrical power in Lower Manhattan prevented crews from pumping the floodwater out as soon as possible. Because of this, subway service was not restored to its normal levels until a week later, a speedy recovery by any measure. One station, South Ferry, was not opened until months later.

NJ Transit, on the other hand, did not recover for months. Many rail lines were not operable for over a month, and Hoboken Terminal did not open until months later. NJ Transit's infrastructure was far more damaged than MTA infrastructure. Some of this is an incidence of geography, of course, but it showed very clearly that NJ Transit should not have been so quick to dismiss the need to plan for climate change adaptation. Officials in New Jersey were clearly aware of the threat of climate change, as evidenced by state programs such as the Blue Acres program, which buys floodplain land from owners who now longer want the deal with the risk of flooding. It seems that the willful ignorance of the threat posed by a hurricane was an isolated incident, and one that certainly will not be repeated.

Adaptation planning needs to become a higher priority so that future damage and suspension of services is minimized. The contrast between the planning that had been undertaken by the MTA and NJ Transit and their recovery times after Hurricane Sandy shows the importance of planning for both extreme weather events and long-term climate change adaptation.

5.2 New Orleans

While, New Orleans' transit agency, New Orleans Regional Transit Agency (NORTA), has not undertaken a climate change planning process, the City of New Orleans, however, has both a Hazard Mitigation Plan and a comprehensive Master Plan that also addresses resilience. They are very detailed documents that address the threat of extreme weather and climate change. Both were developed after Hurricane Katrina struck the city on August 29, 2005.

New Orleans adopted its Hazard Mitigation Plan in December 2005. A FEMA-approved Hazard Mitigation Plan is required in order for a local government to receive funding under the Stafford Act in the Disaster Mitigation Act of 2000. The plan has to be approved by FEMA, the state homeland security office, and city council, and must be updated every five years.

The mission statement of the City's Hazard Mitigation Plan is "to promote, implement, and sustain mitigation measures in Orleans Parish in order to reduce and manage risks to human life, the environment, and property" (City of New Orleans, 2010). The original 2005 Hazard Mitigation Plan identified 11 hazards, and the 2010 update- which was adopted in August 2010- includes 14 hazards. The plan includes both short-term and long-term strategies for addressing the hazards. Some actions are routine actions for City staff, and other actions will be implemented under the Master Plan.

The City of New Orleans Master Plan has a chapter that specifically addresses resilience. Additionally, the Hazard Mitigation Plan is an appendix to the Master Plan, which has the force of law. While this does not force the City to implement projects outlined in the Master Plan, it does mean that all zoning and land use decisions must be consistent with the plan (Goody Clancy, 2010).

The Master Plan does include public transportation-specific goals in the resilience chapter, and would have received a score of 6 in the coded evaluation used in this study.

The lack of congruity in hazard mitigation planning across agencies in New Orleans can seem puzzling, but it is likely an example of the freerider problem as it applies to climate change adaptation planning: the City's Master and Hazard Mitigation Plans sufficiently address so many issues that there is little reason for NORTA to develop a climate change plan of their own. Additionally, NORTA is a regional agency, and weak regional governance could also explain the lack of planning. Overall, New Orleans is a good example of planning for climate change adaptation.

6. CONCLUSION

There is an urgent need for public transit agencies to plan for climate change adaptation, as it is clear that cities and their infrastructure are going to continue to be impacted by the increased intensity of extreme weather events. Flooding is a very threatening effect of climate change since there is nothing city officials can do to prevent flooding. Transit agencies, especially in areas where transportation infrastructure is low-lying, must adapt to the increased risk. The MTA has started a climate change adaptation process that includes a detailed study of what risks are posed to infrastructure and many recommended goals, but it is not an official plan. With its BRSC report, though, the MTA has done much more planning for climate change than any other East Coast transit agency.

What measures might encourage transit agencies to plan for climate change adaptation? The most obvious answer to this question is increased funding. It is unlikely that transit agencies are going to pay for climate change planning processes when public transit budgets are so strained. Instead, state or federal funding is necessary to push transit agencies to develop adaptation plans. Until then, incremental changes to infrastructure will be made via capital programs.

Perhaps a more realistic approach is to focus on short-term hazard mitigation planning, which refers to how entities prepare, deal with, and recover from a disaster. As seen in the comparison of the MTA and NJT and how quickly they were able to recover from Hurricane Sandy, short-term planning is very important, especially in terms of restoring service so that riders can resume their normal schedules. Therefore, one important step that transit agencies could take is to ensure that they have a detailed disaster recovery plan. While this is not the same as outright planning for climate change, it is an adaptation measure, and an affordable one.

Overall, the lack of prioritization of climate change planning is the greatest stumbling block. As seen with New Orleans, and likely what will be observed in the New York City area, hazard mitigation planning efforts are usually prompted by an extreme weather event. Brody observed increase in quality of hazard mitigation plans in Florida to be motivated by previously established policy-making momentum and repetitive loss to specific properties (2003). If this is the case across different states and cities, only time will lead to more transit agency climate change adaptation plans.

Bibliography

Adger, W. N., Arnell, N. W., & Tompkins, E. L. (2005). Successful adaptation to climate change across scales. *Global Environmental Change, 15*(2), 77-86.

Baker, I., Peterson, A., Brown, G., & McAlpine, C. (2012). Local government response to the impacts of climate change: An evaluation of local climate adaptation plans. *Landscape and Urban Planning*.

Brody, S. D. (2003). Are we learning to make better plans? A longitudinal analysis of plan quality associated with natural hazards. *Journal of Planning Education and Research, 23*(2), 191-201.

City of New Orleans. (2010). Orleans Parish 2010 Hazard Mitigation Plan Update.

Goody Clancy. (2010). Plan for the 21st Century: New Orleans 2030. New Orleans: New Orleans City Planning Commission.

Jacob, K., Rosenzweig, C., Horton, R., Major, D., & Gornitz, V. (2008). MTA Adaptations to Climate Change: A Categorical Imperative. *White paper for the MTA BRCS. Accessed August, 25*, 2009.

Jones, R. N. (2001). An environmental risk assessment/management framework for climate change impact assessments. *Natural Hazards, 23*(2), 197-230.

Kaiser, E. J., Godschalk, D. R., & Chapin, F. S. (1995). *Urban land use planning* (Vol. 4): University of Illinois Press Urbana, IL.

Karoly, D. J., Braganza, K., Stott, P. A., Arblaster, J. M., Meehl, G. A., Broccoli, A. J., & Dixon, K. W. (2003). Detection of a human influence on North American climate. *Science, 302*(5648), 1200-1203.

McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J., & White, K. S. (2001). *Climate change 2001: impacts, adaptation, and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change*: Cambridge University Press.

Metropolitan Transportation Authority. (2007). August 8, 2007 Storm Report. New York: MTA.

Meyer, M. D., Amekudzi, A., & O'Har, J. P. (2010). Transportation Asset Management Systems and Climate Change. *Transportation Research Record: Journal of the Transportation Research Board, 2160*(-1), 12-20.

Mills, B., & Andrey, J. (2002). Climate change and transportation: potential interactions and impacts. *The Potential Impacts of Climate Change on Transportation,[US] DOT Center for Climate Change and Environmental Forecasting (*http://climate*. volpe. dot. gov/workshop1002/mills. doc)*, 77-88.

Moser, S. C., & Luers, A. L. (2008). Managing climate risks in California: the need to engage resource managers for successful adaptation to change. *Climatic change, 87*(1), 309-322.

National Research Council Committee on Climate Change & US Transportation. (2008). *Potential Impacts of Climate Change on US Transportation* (Vol. 290): Transportation Research Board.

Navarro, M. (2012, August 22). New York's City Council Adds Climate Change Panels, *New York Times*. Retrieved from http://green.blogs.nytimes.com/2012/08/22/new-yorks-city-council-adds-climate-change-panels/

NCHRP. (2002). Transportation Asset Management Guide: Project 20-24(11) for AASHTO.

New York State Energy Research and Development Authority. (2011). Responding to Climate Change in New York State.

Peterson, T. C., McGuirk, M., Houston, T. G., Horvitz, A. H., & Wehner, M. F. (2008). *Climate variability and change with implications for transportation*: Transportation Research Board.

Thomson, B. D., E.; Eget, S.; Gallagher, L. (2012). Resilience of NJ Transit Assets to Climate Impacts: First Environment, Inc.

Titus, J. (2002). Does Sea Level Rise Matter to Transportation Along the Atlantic Coast? *The Potential Impacts of Climate Change on Transportation*, 135.

Zimmerman, R. (2002). Global Climate Change and Transportation Infrastructure: Lessons from the New York Area. *The Potential Impacts of Climate Change on Transportation, 11*(A17), 91.